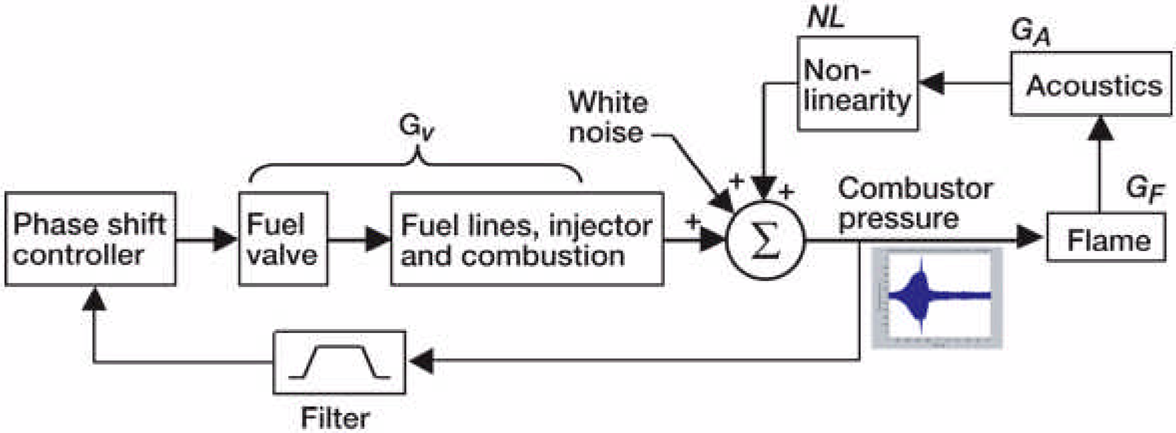
Adaptive Controls Method Demonstrated for the Active Suppression of Instabilities in Engine Combustors

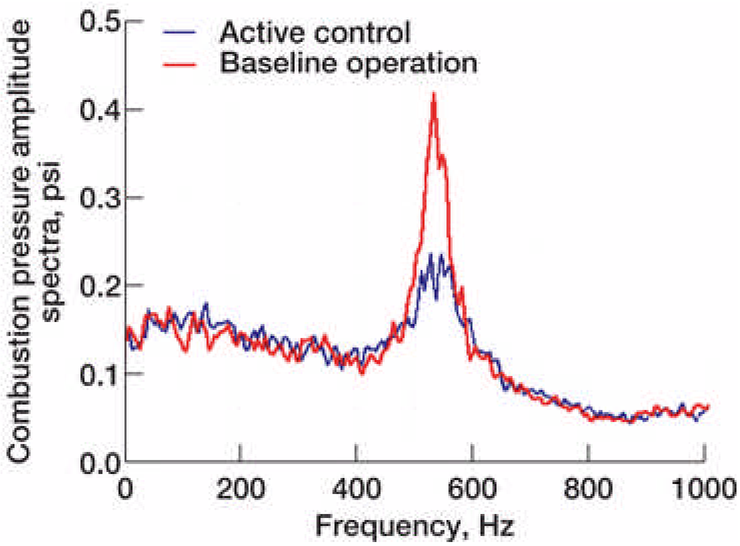


Combustion instability control block diagram. G_V, G_F, and G_A are transfer functions of the associated combustion processes reflected in the figure; NL is a damping nonlinearity that restricts the amplitude of the opened-loop self-excited instability.

Feedback control block diagram of the combustor instability plant. The combustor instability is represented by a self-excitation loop consisting of a summation block whose output is overall combustor pressure. This is fed to a block representing the flame dynamics, which feeds a block of the acoustics dynamics, which feeds a block that provides a soft limiting function (tan h(x)), which feeds back to the original summation block as the instability pressure. This summation block is also fed with wide band noise and combustor pressure due to fuel control modulation. The overall combustor pressure from before is fed back into a band-pass filter, which feeds the phase shift controller, in turn feeding the fuel valve, which feeds the fuel lines, injector, and combustor, which results in the combustor pressure due to the controlled fuel modulation that ends up feeding the summation block.

This year, an adaptive feedback control method was demonstrated that suppresses thermoacoustic instabilities in a liquid-fueled combustor of a type used in aircraft engines. Extensive research has been done to develop lean-burning (low fuel-to-air ratio) combustors that can reduce emissions throughout the mission cycle to reduce the environmental impact of aerospace propulsion systems. However, these lean-burning combustors are susceptible to thermoacoustic instabilities (high-frequency pressure waves), which can fatigue combustor components and even the downstream turbine blades. This can significantly decrease the safe operating lives of the combustor and turbine. Thus, suppressing the thermoacoustic combustor instabilities is an enabling technology for lean, low-emissions combustors under NASA's Propulsion and Power Program. This control methodology has been developed and tested in a partnership of the NASA Glenn Research Center, Pratt & Whitney, United Technologies Research Center, and the Georgia Institute of Technology. Initial combustor rig testing of the controls algorithm was completed during 2002. Subsequently, the test results were analyzed and improvements to the method were incorporated in 2003, which culminated in the final status of this controls algorithm.

This control methodology is based on adaptive phase shifting. The combustor pressure oscillations are sensed and phase shifted, and a high-frequency fuel valve is actuated to put pressure oscillations into the combustor to cancel pressure oscillations produced by the instability.



Amplitude spectral density of uncontrolled versus controlled instability.
Amplitude spectra of the combustor pressure with the uncontrolled combustion instability. The combustion instability shows a peak in the spectra at about 530 Hz. The peak is at about 0.42 psi. The surrounding noise at other frequencies is at about 0.15 psi. The figure also shows the combustion instability amplitude spectra when being controlled by the adaptive phase-shift control method described in the article. The peak using this control method was reduced to about 0.22 psi.

Combustor instability suppression poses a challenging feedback controls problem due to unmodeled dynamics, large dead-time phase shift in excess of 1000°, large-amplitude wide-band noise in comparison to the amplitude of the instability (~ 6/1 ratio for the combustor rig), severe amplitude modulations, frequency and phase-shift randomness, and a system that continuously transitions through inherently unstable operation at increased suppression levels. To overcome these difficulties, NASA researchers developed a sophisticated controls method that does not depend on detailed modeling of system dynamics. The controls method is named "adaptive sliding phasor averaged control." The controller phase continuously slides back and forth inside the boundaries of an effective stability region that lies within a restricted control region in a stationary frame of reference. In this control algorithm, the combustor pressure oscillations are sensed through a band-pass filter to isolate the instability from noise. Then, the filtered pressure oscillations are continuously phase shifted at a rate of 40 Hz in the direction that suppresses the instability and are output to the fuel actuator at a rate of 10 kHz in order to suppress the instability. Also, discontinuous exponential gain modulation and control parameter adaptation is employed.

This active combustion instability control method was shown to reduce thermoacoustic-driven combustor pressure oscillations and was demonstrated for a high-frequency (530 Hz) instability on a single-nozzle combustor rig at United Technologies Research Center. This is the first known successful demonstration of high-frequency combustion instability suppression in a realistic aircraft engine environment. This rig, which emulates an actual engine instability experience, has many of the complexities of a real engine combustor (i.e., an actual fuel nozzle and swirler, dilution cooling, etc.).

Bibliography

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Find out more about this research:

Active Combustion Control: http://www.grc.nasa.gov/WWW/cdtb/projects/combustor/
Glenn's Combustion Branch: http://www.grc.nasa.gov/WWW/combustion/

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